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Pumped-storage in Bulgaria – developments, current situation and some perspectives

Dimitar Kisliakov*

Dept. of Hydraulic Engineering, UACEG, 1 Hr. Smirnenski Blvd., 1046 Sofia, Bulgaria

Abstract

The objective approach requires that the hydropower development cannot be analyzed outside the economical and overall national development of a particular country during a considered time period. Yet the current presentation addresses exclusively the Hydropower development in Bulgaria, and moreover, concentrated only on the features of pumped-storage as a reliable and still highly competitive energy storage technology.

The pumped-storage as part of the hydropower development in Bulgaria and the situation as in 1989 are introduced. The overall development in Bulgaria after November 1989 and its impact on both running and future hydropower and pumped-storage projects are shortly presented. Particular features of the current situation are outlined. Furthermore, special attention is paid to the national legislative environment in the frame of the crucial policies, strategies and directives of the European Union.

Finally, some ideas and project possibilities for the use of the still available pumped-storage potential in Bulgaria are discussed in more detail. The work ends with conclusions on the Bulgarian hydropower development with respect of pumped-storage mainly after 1989. Needed research activities in particular fields are identified for a possible future pumped-storage development in Bulgaria as an EU member state in the sense of global electricity market conditions.

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Keywords: Hydropower; Pumped-storage; Bulgaria

1. Introduction

In fact, being the largest-capacity form of grid energy storage still available worldwide, pumped-storage plays an important role in peak generation and energy storage in an electric power system (EPS). Hydropower development

* Corresponding author. Tel.: +359-2-963-5245, ext. 490 (via operator); fax: +359-2-866-8287.
E-mail address: dkisliakov@abv.bg

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in general occurs in synergy with the deployment of the other renewable energy sources. Reservoir and / or pumped-storage power plants help operating an electric power system in a safe and flexible way by providing balancing generation and load conditions for other renewables (e.g., wind and solar photovoltaics) [1,2,3].

The objective approach requires that the hydropower development cannot be analyzed outside the economical and overall national development of a particular country during a considered time period. Yet the current study addresses exclusively the Hydropower development in Bulgaria, and moreover, concentrated only on the features of pumped-storage as a reliable and still highly competitive energy storage technology in the field of hydro power.

In-depth political and economic changes started in Bulgaria in November 1989. It is well known that the power sector has a special place in the strategic development of a national economy. The power industry serves the strategic overall economic development but only though this development it has its own economic purpose. In this sense, on the eve of the changes in 1989, Bulgaria had a well-developed power system with sufficient capacity of the producing, transfer and distributing equipment and networks. This system was completely autonomous and ensured the national energy independence. Moreover, Bulgaria was a serious and permanent energy exporter.

2. Hydropower and pumped-storage development in Bulgaria – historical background

The water power use in Bulgaria has its long and prosperous history – the first water power plant started its operation in 1900. The period of decisive and most intensive hydropower development was after the Second World War. In these decades, all large hydropower systems in Bulgaria with large reservoir storage volumes and large installed capacities were built. Due to the relatively quite limited water resources of the country, they all are characterized by multi-purpose use of these resources and transfer of water between different catchment areas. All these highly complex systems were developed, designed and built by Bulgarian engineers.

At the end of 1989, approximately 90 water power plants were in operation in Bulgaria, with a total installed capacity of nearly 4480 MW. The following ones of them were pumped-storage power plants (PSPP), being still in operation:

- PSPP “Kalin” (Bulg.: “Калин”) represents the most upper stage of the first Bulgarian large hydropower cascade “Rila” (Bulg.: “Рила”). The cascade of 4 power plants was built in the period 1925 – 1952. From 1925 to 1946, owner, designer and contractor of the facilities was the “Granitoid” JSC. After 1990, the ownership of the hydropower cascade was restituted. PSPP “Kalin” is in operation since 1946 and has one three-component unit with an average capacity of 4.0 MW. The one-nozzle Pelton turbine works with a net head of 740 m and a discharge of 650 l/s. The seven-stage pump operates with 500 l/s at a head of 860 m. An innovative solution with another pump ensures the necessary suction head for the main pump. Thus, no underground powerhouse was necessary.
- PSPP “Orfey” (Bulg.: “Орфей”) is a dam power plant at the toe of the highest dam in Bulgaria “Vucha” (Bulg.: “Въча”) on the Vucha river. The power plant is in operation since 1975. It has 4 machine units with an installed capacity of 40.0 MW each. One of them is reversible and can be operated in both turbine and pumping modes.
- PSPP “Belmeken” (Bulg.: “Белмекен”) is the most upper stage of the largest Bulgarian hydropower cascade “Belmeken-Sestrimo” (Bulg.: “Белмекен-Сестримо”) in operation since 1974. Its 5 units with Pelton turbines have a total installed capacity in turbine mode of 375.0 MW at a head of 690 m and with a water discharge of 62.5 m^3/s. Two units are equipped with five-stage pumps with totally 104.0 MW at a head of 705.0 m and Q_Σ = 13.5 m^3/s.

The extension of the “Belmeken-Sestrimo” cascade with the underground PSPP “Chaira” (Bulg.: “Чаира”) was launched in the 1970-ies. This PSPP has 4 reversible units with a total installed capacity of 864 MW in turbine mode and of 788 MW in pumping mode. The average head is 700 m, the discharge in turbine mode is 36.0 m^3/s, and in pumping mode 29.5 m^3/s. The first lot of the system comprising two machines was completed in 1995, and the second lot – in 1999. In this period, the units of PSPP “Chaira” were the reversible machines with the highest head in the world.

One further specific feature of the Bulgarian hydropower development in the field of pumped-storage is that in some large Hydraulic Engineering systems, some pumping stations were operated together with storage hydropower

plants as pumped-storage facilities in the common EPS. This enabled a better management of both the load in the EPS and the water resources in the affected catchment areas, of course – with clearly defined optimization priorities.

It should be mentioned here that many further multi-purpose systems with intensive hydropower use were developed and analyzed but remained not built by 1989 due to different reasons. In the field of pumped-storage, these were the large projects „Shumen" (Bulg.: "Шумен" in North-Eastern Bulgaria), „Lakatnik" (Bulg.: "Лакатник"in the gorge of the Iskar river where it crosses the Balkan mountain), „Trun" (Bulg.: "Трън" approximately 40 km to the North-West of Sofia) and „Koprivshtitsa" (Bulg.: "Копривщица" approximately 50 km to the East of Sofia).

3. Overall development of Bulgaria after 1989 and its impact on Hydropower

Without any particular comments on the economic development in Bulgaria after 1989, it can be summarized that in some form, private property of the means of production and market economy were introduced. Thus, the national power industry in general and the hydropower in particular became subject to powerful privatization interests as strategic sectors with tremendous material values. Many hydropower cascades and power plants were sold by the state instead of being operated as a concession. A short analysis of the situation in this field was performed in [4].

Currently, the Bulgarian transmission grid is part of the Synchronous Grid of Continental Europe (formerly UCTE grid) comprising 29 transmission system operators of 24 countries. By 2011, the total length of the electricity transmission grid in Bulgaria was 15213 km, with the following structure:

- Overhead transmission lines: 400 kV with a total length of 2451 km; 220 kV with a total length of 2805 km; 110 kV with a total length of 9957 km.
- Transformer substations: 32 HV/HV substations with a total transformer capacity of 15888 MVA; 257 HV/MV substations with a total transformer capacity of 15243 MVA.
- Switching stations: one 400 kV switching station; one 110 kV switching station.

The structure of the installed generating capacities by types of plants in 2011 is presented in Fig. 1 [5]. Table 1 gives a summary of the production and deliveries of electricity in the first months of 2014. The participation of the renewable energy sources (RES) in the electricity generation can be traced for the last few years in Table 2. The perspectives for the future development of the generation mix can be summarized according to [6] in Table 3.

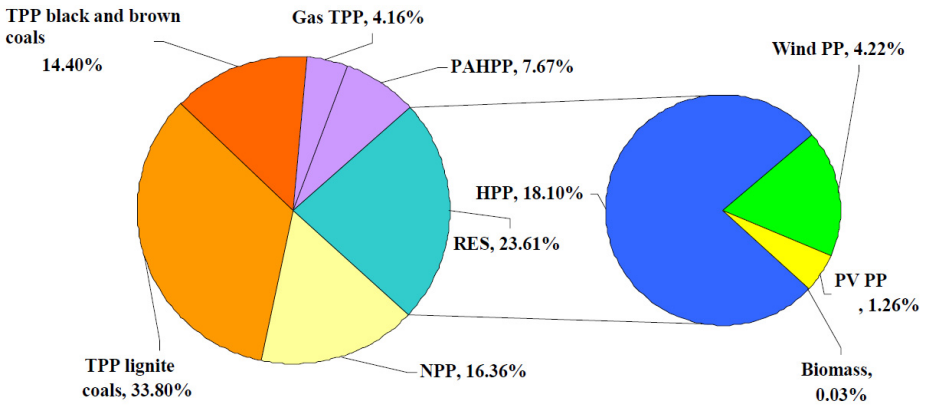

Fig. 1. Structure of the installed capacities by types of plants in 2011 [5]

A problem of crucial importance for the structure and the operation modes of a power system are the regulating capacities, i.e. PSPP, moreover, in a close relation to the long-term industry development and the increasing contribution of RES, Table 2. Recently [7], the issued licenses in Bulgaria for energy production from renewable

sources are, as follows: wind power – 2017 MW; photovoltaics – 230,1 MW; biomass – 15 MW, i.e. totally – 2262,1 MW. Here, the following features have to be outlined:

- In general, the energy consumption in Bulgaria by the industry and the energy export decreases [8]. Compared to 2012, the absolute maximum load in 2013 decreased by 10.37%, and the absolute minimum one – by 14.31%. The total annual consumption decreased by approximately 2.1% with respect to 2012.
- The structure of the energy production mix and its development are, to a large extent, a result of a legislative initiative launched on EU level. Thus, it is characterized by an intensive increase of the portion of the renewable sources.
- The quality of the energy from the above mentioned renewable sources is relatively low [9] in the sense of electrical power system parameters, and all power system components have to consider this fact. Hence, the proper operation of the power system needs regulating capacities.

Table 1. Production and deliveries of electricity for 2014 in GWh (source: NSI)

	Links	months of 2014				
		I	II	III	IV	V
Gross production	1	4690	3950	3699	3583	3422
Net production	2	4234	3572	3359	3268	3116
Import	3	334	219	491	307	311
Export	4	1107	784	929	934	940
Used for the internal market	5=2+3-4	3461	3007	2921	2641	2487

Table 2. Electricity in Bulgaria generated from renewable sources in percentage (source: NSI)

2004	2005	2006	2007	2008	2009	2010	2011	2012
9,5	9,8	9,9	10,0	10,7	12,1	13,7	13,9	17,0

Table 3. Targets for the future electricity generation in Bulgaria [6]

Indicator	2005	2010	2015	2020	2030
Genaration (TWh), of which:	44	39.7	43.2	49.7	58
Nuclear	18.6	14.7	14.7	22.3	30
Hydro + Wind	4.3	4.5	5.2	5.8	6.9
TPP incl. biomass and new gas capacities	21	21	23.4	21.6	21.2
Consumption (TWh)	36.4	35.5	37	39.3	45
Export (TWh)	7.6	4.2	6.2	10.4	13

In this connection, the actual situation with pumped-storage is complicated. On one hand, the energy production from renewable sources in fact needs pumped-storage as a regulating capacity. On the other however, the current market conditions, especially in the EU-countries, have in fact frozen the active projects in this field.

In Bulgaria, a clear vision exists on the pumped-storage development. Since the time of completion of the PSPP “Chaira” in the 90-ies, the strategic concept in the Bulgarian power industry is that the country does not need any more PSPP [6]. However, the recent European development trends in this field show a remarkable discrepancy between the increase of the proportion of renewable energy sources and the need for regulating capacities.

Currently, the Bulgarian National Electricity Company (NEK EAD) is owner of 30 hydropower plants (including PSPP) with a total installed capacity of 2713 MW in turbine mode and 937 MW in pumping mode. In 2011, the total production was 2847 GWh, and the consumption in pumping mode was 1199 GWh.

4. Legislative framework and market conditions

On one hand, despite its decisive role as an inevitable source of peak energy and reactive power, large hydropower (i.e. above 10 MW) is not promoted by the long-term EU energy policy as a renewable source of energy. On the other, large hydropower is indeed recognized as renewable energy in respect of its participation in the total energy mix. Pumped-storage proved, after the market boost of wind and solar power, to be the only yet available and enough powerful source of regulating power in an EPS.

For a short summary and discussion of the current state of the European and national legislation in the fields of both environment and energy from RES, we would refer here to the results of the research project RIVERS [10].

In the last twenty five years, Bulgaria substantially re-organized its energy sector in the frame of the newly established market conditions. As member state of the European Union (EU) and in response to the latter's rapidly developing legislative base, Bulgaria intensively prepared the corresponding national package of acts and strategies in both fields of Energy economy in general and particularly of Renewable energy sources. Of course, this is a dynamic and ongoing process, especially with respect to the formulated hard goals of the "20-20-20" shortfall.

At the end of January 2014, the balancing market was established in Bulgaria and has officially been active from 01.06.2014. This was an important step required for the liberalization of the Bulgarian electricity market. These intensive developments resulted in quick and deep changes in the structure, participants and regulatory conditions of the Bulgarian energy market, for which many of the involved parties were not enough and well prepared.

Furthermore, under the developing electricity market conditions in Bulgaria, the generation from RES (incl. small hydropower) has been promoted compared to the large storage and pumped-storage hydropower plants by means of the feed-in prices. These conditions placed the latter hydropower plants and their overall owner – NEK EAD in a very unfavorable position with respect to the long-term possibilities for operation, maintenance and further development of these large systems of highly demanding facilities. For example, for the new price period 01.07.2014 – 30.06.2015, the price of electrical energy from large HPP (i.e. with an installed capacity of over 10 MW) and PSPP in turbine mode owned by NEK EAD is determined as 73.54 BGN/MWh [11]. In pumping mode, these power plants are regarded as regular consumers, and their owner has to pay for grid access and energy transmission. This owner may only subsequently claim for compensation of these expenses. For comparison, the feed-in price of low-head (i.e. up to 15 m) run-of-river SHPP with an installed capacity in the range of 200 kW – 10000 kW is 236.92 BGN/MWh [12]. 1 EUR = 1.95583 BGN.

The short overview of the Bulgarian legislation in the frame of the EU legislative environment in the field of electricity networking and marketing [4,6,13,14,15,16] leads in summary to some main conclusions, as follows:

In the European legislation, only "small hydropower" is considered a renewable energy source. However, there is no precise definition of small hydropower. Usually, the installed capacity – up to 10 MW according to the European Small Hydropower Association (ESHA) is referred to as such a criterion. In Bulgaria, the State Water and Energy Regulatory Commission (SWERC) introduced the capacity level of 10 MW [7]. We share the opinion, however, that the definition of small hydropower should be based on quite different criteria [17].

The hydropower and pumped-storage development cannot be treated separately from the integrated water resources management. On one hand, the increasing participation of the RES in electricity generation will also increase the role of storage HPP and PSPP for regulating the generation power fluctuations caused by wind and solar units. On the other however, the interests of all other water users have to be considered as well, because in general, all large reservoirs in Bulgaria are for multi-purpose use. This fact considerably increases the complexity of the objective functions in both problems, respectively – for dispatching the electric power system and for optimal water resources use. The development of a common database in the field of Water in all its aspects and a common platform with a corresponding administrative interface for institutional cooperation in this field would enable a substantial improvement of the overall water management administration, combining both coordination of institutional activities and regulating documents. Of course, this would be a challenging administrative task requiring long processing time and a large institutional potential. In Bulgaria, its necessity is however obvious, because some striking examples exist of contradiction between small private interests based on perfect particular contracts and the national interest in water, used as a strategic resource.

The actual electricity pricing in Bulgaria places the large storage and pumped-storage hydropower capacities, despite their unrivalled potential for supporting the EPS parameters, in an unfavorable long-term position with

respect to both all other participants on the market and the possibilities for operation and maintenance of their own facilities. Main factors contributing to the overall "financial unsustainability" of the Bulgarian power sector can be summarized according to [18] in the following. Also, some necessary measures are proposed there.

- Some hydroelectricity is being priced artificially low to accommodate RES at high feed-in tariffs;
- The system is not dispatched at least costs due to some "must-run" plants;
- The nuclear generation does not include the costs for decommissioning of existing plants, long-term fuel storage, nor externality costs;
- Co-generators sell power at preferential power prices and buy back cheaper power for their own use;
- Adequate power capacity for domestic use, but administrative constraints to exporting surplus power;
- High preferential tariffs paid to "co-generation" plants imposed by law;
- Costs of long-term Power Purchase Agreements.

5. Some recent projects and future perspectives for the pumped-storage hydropower in Bulgaria

In spite of the official political formulations regarding the long-term development of the power industry in Bulgaria, there is still a substantial hydropower potential available for the future development of hydropower and, in particular, pumped-storage regulating capacities. The main such possible projects with potential influence on the development of large regions are, as follows:

- The "Yadenitsa" (Bulg.: "Яденица") dam [19,20]: The necessity for the extension of the lower basin of the PSPP "Chaira" was identified long before the completion of the project in the 90-ies. This new reservoir will be connected with the lower basin of the PSPP "Chaira" by a reversible pressure tunnel with a length of 6.5 km and a diameter of 7.0 m. The building of the dam "Yadenitsa" would enable a considerable prolongation of the operation of the existing PSPP in both turbine and pumping modes, currently limited by the lower basin volume.
- Hydropower use of a part of the annual run-off of the Mesta river (Bulg.: Места) [21]. Mesta is one of the Bulgarian rivers with most abundant run-off. The problem of the possible use of its water resources is extremely complex, moreover, Mesta is a transboundary river flowing further in Greece. However, such a transfer of a part of this run-off to the above mentioned dam "Yadenitsa" would not affect the conditions of the Bulgarian-Greek agreement.
- Possible use of a part of the run-off of the Struma river (Bulg.: Струма). There are many developments long before 1989 regarding the possibilities by transferring part of the annual run-off into other catchment areas. The possible pumped-storage potential of some of these studies is remarkable. None of the crucial national documents for the strategic energy sector development or water management even mentions these possibilities. Unfortunately, it is not difficult to identify certain long-term interests behind this lack of formulations, however, not Bulgarian national ones.

6. Conclusions

Based on the short presentation of the Bulgarian hydropower development with respect of pumped-storage mainly after 1989, the following conclusions can be drawn:

- The substantial changes of the structure and parameters of the industry in Bulgaria after 1989 lead to serious consequences for the energy producing capacities in the country, in particular for the hydropower and pumped-storage development.
- The accepted national obligations within the EU require an increase of the part of the renewable sources in the energy mix. In this regard, the hydropower and the pumped-storage in particular offer unique possibilities for both base and balancing energy, without which the wind and photovoltaic energy makes less sound sense.
- In Bulgaria, considerable possibilities still exist for the complex use of the limited water resources, including by large capacity hydropower systems. The feasibility of such projects based on their complex influence on the national electricity network and therefore on the modern electricity market may be expected only to increase.

A need for research activities exists in the following fields in terms of global boundary conditions of the electricity market within the EU for a particular pumped-storage development:

- EU energy market analysis: regional characteristics, structure of the energy mix and its development trends in different scenarios, modern technologies for energy storage and the specific role of pumped-storage in this regard for ensuring reliability of the EPS parameters for different mix structures have to be investigated.
- Electric power system conditions: the position of a particular power system within the EU electricity network and in the actual regulative environment, the specific features and interface conditions, the planning and management of the operational regimes have to be analyzed.
- Common operation of pump-storage and renewables: a comparison of pumped-storage and other modern technologies for energy storage, common operation of such storage technologies with renewable energy sources and pumped-storage may be formulated as tasks for future research.

The following issues have to be carefully investigated in connection with any particular further pumped-storage project in Bulgaria: a need for research activities exists in the following fields in terms of global boundary conditions of the electricity market within the EU for a particular pumped-storage development:

- Local (regional) market analysis: the specific structure and conditions of the liberated energy market on the Balkan Peninsula with its structure of the energy mix, expected development trends and interface conditions among the national electric power systems.
- Technical solutions: a survey and analysis of the national and current state-of-the-art knowledge regarding the application of specific technical solutions (in terms of both system and equipment components) for different system schemes and operational conditions.
- Feasibility analysis: a specific geographic and actual market characteristics of a particular investment project for pumped-storage development in connection with the expected long-term development of the renewable energy sources use and the formulated strategic EU energy targets.
- Environmental impact: with regard to the continuously developing European environmental legislation and its particular national implementation, all project developments in the field of Hydropower should serve, with highest priority, the sustainable environmentally consistent regional and national development.
- Water resources: the problem of the possibilities for further hydropower development in general cannot be treated separately from the much more general problem of water resources management in terms of resource management of strategic national and common wealth importance.

Furthermore, the social acceptance of large hydropower projects is a special and difficult problem. However, the effort to persuade the public to accept such projects would be a major institutional capacity building issue and should be continued for the sake of the future generations. This matter is a complicated and sensitive issue. On one hand, the so-called large hydropower projects are considered neither sources of renewable energy nor acceptable from the viewpoint of modern European environmental and social values. On the other however, such projects always play a distinct role in the overall development of a region or a country. In this regard, we consider the initiative and the responsibility of the state administration (and the respective institutional building) as being of crucial importance for the following activities:

- Clear identification and presentation of all related interests with a special emphasis on the strategic national one(s) – particularly relevant for Bulgaria in cases of projects related to trans-boundary catchment areas. Examples: any activities in the catchment basin of the Struma river, prevented so far only by foreign interests, and the recently promoted project for a dam near the border on the Tundzha (Bulg.: Тунджа) river, which would serve explicitly and solely foreign interests;
- Organizing and involving all concerned parties into a constructive dialogue and leading this dialogue. All relevant stakeholders have to be involved in it, in order to achieve, by means of intensive and fruitful discussions among experts and state administration, a coherent, streamlined view on the perspectives of the particular project for the region and the country.

- Organizing and conducting all necessary investigations preceding any project development, towards ensuring objective and competent decision-making with a long-term perspective. In this process, not only high-ranking experts of different subjects are involved, but also the state administration. The action aims at obtaining unequivocal results from the necessary investigations, which will help deriving a sound and solid base for further decision-making, be it on expert or political level. By participating in this process, the representatives of the state administration enjoy the opportunity of being engaged in both a cross-level decision-making and its reasoning, and are thus able to develop further capabilities towards successfully handling similar complex issues. This is a singularly target-oriented process of institution building on national level.

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